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Systematic Map Protocol

Title
How have allelopathic plants been used within integrated pest management systems to control European crop pests in arable and field vegetable systems in temperate climates?

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Secondary metabolite; biopesticide; agriculture; crop protection; allelochemical

Background
Agriculture can meet the growing global demand for food (1) either through intensification or expansion of land use. The latter would result in an ever higher rate of deforestation (2), while the former has the potential to cause widespread environmental harm as intensification has historically meant higher inputs and monocultures (3). The overuse of pesticides in particular has caused degraded soils, loss of biodiversity, and water contamination (4). Integrated pest management (IPM), as a tool for sustainable intensification, offers a potential solution and a middle ground between maintaining yields while reducing pesticide use (5). Allelopathy has been demonstrated to be an effective form of IPM and a source of biopesticides which offer benefits over conventional pesticides such as biodegradability, high selectivity and low human toxicity (6). Implementation of allelopathy on farms and their use in biopesticides remains low (7), despite a growing body of evidence as to it's effectiveness and benefits. Therefore, this research aims to map allelopathy research and to create a database of the results in order to fulfil three aims. Firstly, to reveal areas for potential future research by highlighting gaps in the scientific literature and identifying evidence clusters where there is sufficient quantity of studies to perform systematic reviews. Secondly, as a companion planting directory for farmers looking to utilise allelopathy within IPM. There currently exists several companion planting databases created for home gardeners (8–10), however these are not well substantiated by scientific evidence, are not aimed at commercial agriculture and do not discuss different modes of application, such as intercropping or ploughing of residues into the soil. Thirdly, the database will highlight potential sources of biopesticides. To this end key allelochemicals will be identified and any links to human toxicity will be noted in a brief summary of basic chemical data.

Theory of change or causal model
Allelopathic plants produce secondary metabolites which influence the growth, health or reproduction of other organisms. These secondary metabolites can have a pesticidal effect on neighbouring organisms from multiple taxa including plants, fungi, insects and bacteria (11). The underlying assumption of this protocol is that allelopathy is broadly utilised in IPM systems as a form of biological control. The research is expected to detail how allelopathy is being implemented and which plants are effective for which pests.

Stakeholder engagement

This protocol was developed as part of an application for a scholarship from Certis Europe, a crop protection specialist company, who wanted to fund research into crop protection. The initial question was proposed by the first author and the project was developed through discussions with experts in pest management and agroecology, as well as Certis Europe.

Objectives and review question

This systematic map aims to describe the current research into allelopathy within IPM systems in temperate European arable and field vegetable systems in order to highlight areas for future research, facilitate farm level implementation and describe potential biopesticides. The primary question posed is: How have allelopathic plants been used in IPM systems to control European crop pests in arable and field vegetable systems in temperate climates? The secondary question of this paper is: Which methods of allelochemical application within IPM systems have been investigated?

Definitions of the question components

Population: European arable and field vegetable crop pests in temperate climatic zones. Specifically, plant and invertebrate pests of the following crops common to temperate Europe: cereals (wheat, barley, triticale, oats and rye), corn, root crops (potatoes, sugar beet, onions, garlic, carrots, leeks), legumes (dry peas, beans, lentils, chickpeas, soya beans), and brassicas (white cabbage, cauliflower, broccoli, oilseed rape). Intervention: Allelopathic plants or plant-derived allelochemicals. Comparator: Different implementations of the allelopathic plants within integrated pest management systems (e.g. companion cropping, intercropping, ploughing of residues into soils, artificial applications), or, an alternative or no allelopathic plant. Outcome: Must relate to the impact on the crop (e.g. growth, yield) or the pest (e.g. changes to fitness, reproduction, absolute numbers, mortality of pest species).

Search strategy

A database will be produced using the following methods and will document the publications assessed. The methods used are based on James, L., Randall, N. and Haddaway, N. (2016) (12) and the Collaboration for Environmental Evidence Guidelines (13). ROSES reporting standards (14) have been adhered to and can be found in additional file 1. The searches will be conducted using the bibliographic databases and search string defined in section 8.1. The results from each search will be imported to the reference manager Mendeley and details of each search will be recorded including date, time, number of results, and precise search string used. There will be no search restrictions regarding the published date of articles as there may be relevant historical and modern literature, but the publication language will be restricted to English. Search terms were identified from the PICO analysis, a list of benchmarking articles discussed in section 8.4 and in discussions with experts in pest management and agroecology. The search string was developed using a scoping study found in additional file 2.

Bibliographic databases

The search for relevant literature will be conducted using the following bibliographic database: 1. Web of Science (WoS) All Databases (https://webofknowledge.com) which includes: 1a. Web of Science Core Collection (http://webofknowledge.com/WOS) 1b. BIOSIS Citation Index (http://webofknowledge.com/BCI) 1c. CABI: CAB Abstracts and Global Health (http://webofknowledge.com/CABI) Web of science is accessed through Harper Adams University subscription. The search string to be used is as follows: (allelopath* OR allelochemical* OR "secondary metabolite*" OR glucosinolate* OR isothiocyanate* OR phenol OR phenols OR phenolic OR alkaloid* OR terpenoid* OR benzoxazinoid*) AND (IPM OR "integrated pest management" OR "weed management" OR "pest management" OR "weed suppression" OR "pest suppression" OR "weed control" OR "crop protection" OR "plant resistance" OR biofumig* OR "insect repell?nt*") AND (arable OR "field vegetable*" OR Cereal* OR Wheat OR Barley OR triticale OR oat* OR rye OR "root crop*" OR potato* OR "sugar beet" OR onion OR garlic OR carrot* OR leek* OR corn OR maize OR brassica* OR legume* OR agricult* OR "agricultural pest*" OR "plant pest*" OR "insect pest*" OR "soil-borne pest*" OR "parasitic weed*" OR "dry peas" OR bean* OR lentil* OR chickpea* OR "soya bean*" OR "white cabbage" OR cauliflower OR broccoli OR "oilseed rape" OR "invertebrate pest*" OR nematode*) In WoS, a topic search will be conducted and this search string will be input as written.

Web-based search engines
N/A

Organisational websites
A further search will be conducted using the following organisational website: AGRIS, UN FAO (https://agris.fao.org/agris-search/index.do) The search language will be set to English and the search string defined in section 8.1 will be input as written.

Comprehensiveness of the search
The comprehensiveness of the search string was examined in the scoping study using ten benchmarking articles known to be relevant to the map, which can be found in additional file 3. When articles were missing from the results of a search string they were reviewed for additional relevant search terms, which were then added to subsequent searches. The final search string found nine of the ten articles in the WoS databse and the remaining one in the AGRIS database. The comprehensiveness of the main searches will be further examined, alongside a search for grey literature, using the defined search string in Google Scholar and taking the first 500 results. These will be screened and cross-referenced with the previous results to highlight any relevant published articles missed by the initial searches and any relevant grey literature which will then be added to the database.

Search update
N/A

Screening strategy
The articles returned by the searches will be screened using EPPI-Reviewer (15). Primary screening will be by title to remove duplicates. The quantity of duplicates will be noted however these articles will not be recorded in a separate file. The remaining articles will then be screened against the inclusion criteria by title, then by abstract. Where available and if necessary, the full texts will then be screened. Where full texts are not available through WoS and AGRIS, they will be accessed using HOLLY (Harper Adams University Online Library). Articles where the full text is inaccessible will be included if the abstract provides sufficient information to satisfy the inclusion criteria. Conflicting papers will be included and mention will be given to the limitations of the evidence for that particular chemical. Secondary research, such as reviews and meta-analyses, will be included in a separate file and will be used as a source for additional primary research. Any articles identified by these sources which satisfy the inclusion criteria will be added to the systematic map. Should the quantity of included studies exceed the limitations of the timeframe, the eligibility criteria will be reviewed and made more restrictive, for example, by specifying insect pests only and therefore excluding weed pests.

Eligibility criteria
The eligibility criteria were determined based on the PICO analysis, stakeholder interests and the time restrictions of the study. Eligible subjects: studies which investigate the effect of any allelopathic plant or plant secondary metabolites (also called allelochemicals) on agricultural pests

found in temperate Europe. Specifically weed and invertebrate pests associated with the crops defined in the PICO analysis: “cereals (wheat, barley, triticale, oats and rye), corn, root crops (potatoes, sugar beet, onions, garlic, carrots, leeks), legumes (dry peas, beans, lentils, chickpeas, soya beans), and brassicas (white cabbage, cauliflower, broccoli, oilseed rape)”. The studies need not have been conducted in Europe, however they must have been conducted in a temperate climatic zone according the Köppen-Geiger climate classification (16). Other pests, such as pathogens and fungi, will not be specifically searched for however should a study examine pathogen load in response to allelopathy inhibiting a plant or insect vector, such studies will be included. Studies which solely examine pathogens or fungi will not be included, however, studies which examine the effect of allelopathy on a host Eligible interventions: a pesticide affect from allelopathic plants or plant derived allelochemicals. Eligible comparators: different methods of allelopathy application or different allelopathic plants/allelochemicals or the absence of allelopathic plants/allelochemicals. Eligible outcomes: a measurable or observable affect on the crop (e.g. growth, yield) or the pest (e.g. mortality, reproduction). Eligible study designs: all study designs will be included, including but not limited to laboratory trials and before and after field studies.

Consistency checking
A random sub-set of 5% of articles will be selected from the search results and will be used to check consistency of the screening. The size of this subset may decrease if the quantity of articles is too great for the timeframe. Both authors will screen the articles to abstract against the inclusion criteria, however, only the first author. will conduct the full screening. Cohen’s Kappa coefficient will be used to determine the consistency of decision making and a value of greater than 0.6 will indicate acceptable agreement. Where authors have differed, the inclusion criteria will be reviewed and adjusted accordingly.

Reporting screening outcomes
A ROSES flow diagram will be produced to report the outcome of the screening. Articles excluded at title and abstract will be detailed in one file, while another separate file will record articles excluded at full text with explanations of their exclusion.

Study validity assessment
Contradictions and discrepancies in the publications will be noted as evidence of the need for further research, however a detailed critical appraisal will not be carried out. Systematic maps do not require a critical appraisal, nevertheless, details such as study type and design will be recorded to facilitate any future systematic reviews. It will also be noted in the final report that a lack of critical appraisal is a limitation of this study.

Consistency checking
N/A

Data coding strategy
If the timeframe, quantity of articles and access allows, full text data will be extracted according to the data coding strategy set out in additional file 4, otherwise studies will only be coded to abstract. All studies will have the following meta-data recorded: • Bibliographic information • Study background • Study details including: o Population(s) and intervention(s) tested o Crop(s) affected o Form of comparator(s) o Study outcome Where studies have compared different methods of application of allelopathy, the types of applications tested will also be recorded. For studies conducted in the field, details of the farming system, climate and location will also be recorded. If an allelochemical’s toxicity to humans is discussed this will also be included in the data coding however no additional research will be conducted to find this information independently.

Meta-data to be coded
The full data coding strategy can be found in additional file 4.

Consistency checking
Coding will be performed by the first author, with a subset of 5% of studies checked for coding consistency by both authors. Should there be substantial disagreement, the coding criteria will be reviewed and a further subset of 5% of studies will be rechecked for consistency. This will be repeated until the consistency reaches a minimum of 90% similarity. The following missing information will be found through independent internet searches: Latin or common names for crops and pests, climate classifications, and crops affected by the studied pest. Other missing relevant information will be coded as “Not specified”, because the timeframe does not allow for contacting authors for information, and information that does not apply to a specific study will be coded as “NA”.

Type of mapping
A full written report will be produced to document the methods and results of the research and will accompany the systematic map database. The searchable database will be produced using Microsoft Excel and will contain a data dictionary, all included studies and all available details from the coding strategy. This will be published as a supporting file with the systematic map report. The results of the searches are likely to be highly heterogeneous as allelochemicals originate from, and apply to, a wide variety of organisms and multiple comparators are accepted in the inclusion criteria. As such, synthesis of the studies will be purely narrative, in line with systematic map protocol (12).

Narrative synthesis methods
Descriptive statistics will be used to characterise the systematic map, while evidence clusters and gaps in the literature will be identified via heat maps: tables of two variables showing the number of studies examining their interaction. Potential variable combinations depend on the search results but are expected to be; allelopathic plants and crop pests; allelopathic plants and methods of application; allelopathic plants and allelochemicals.

Knowledge gap identification strategy
The systematic map database will enable clusters to be identified. The final report will detail any gaps or clusters identified by the heat maps described in section 12 and will include any relevant recommendations.

Demonstrating procedural independence
CK has no prior publications and will be conducting the research. The random subsets of articles NR will check for consistency will not include papers published by NR.

Competing interests
The authors declare that they have no competing interests.

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CK received funding in the form of a scholarship from Certis Europe through Harper Adams University. Certis have no role in any aspect of the study design, collection, analysis or interpretation of data or in writing the manuscript.

Author’s contributions
The primary question and research objectives were conceptualised by CK. NR, as the subject expert, proposed the systematic map approach, defined the PICO terms and discussed, guided, and reviewed the study design and methodology. CK drafted the initial protocol, performed the scoping

study, and wrote the final manuscript. Both authors read and approved the manuscript.

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